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Effect of Processing Conditions on the Formation of ODS Layer on Zr-based Tubes

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1. Introduction

Accident tolerant fuel (ATF) cladding is being developed globally after the Fukushima accident with the demands for the nuclear fuel having higher safety at normal operation conditions as well as even in a severe accident conditions. Korea Atomic Energy Research Institute (KAERI) is one of the leading organizations for developing ATF claddings [1,2]. Various ATF concepts have been developed via a national R&D project with the grant of Ministry of Science and ICT from 2012. Recently, a new project was launched to develop the irradiation test rod using ATF pellets and cladding in collaboration with research institute, nuclear fuel vendor, and universities under the funding of Ministry of Trade, Industry and Energy. This paper explains one of concepts being developed in the latter project, i.e., zirconium alloy based cladding consisting of oxide dispersion strengthened (ODS) layer and surface coating.

The ODS treatment was proposed to increase the strength of the Zr-based alloy up to high temperatures [2-7]. High-power laser beam was exposed on the zirconium surface previously coated by oxides (typically Y_2O_3). The dispersed oxide layer was formed by the penetration of oxide particles into Zr alloys. According to our previous investigations [3-7], the tensile strength of Zircaloy-4 was increased by up to 20% with the formation of a thin dispersed oxide layer with a thickness less than 10% of that of the Zircaloy-4 substrate. In this paper, the ODS treatment was performed using developing fuel cladding tubes by KEPCO NF. It is investigated the formation of ODS layer and mechanical properties depending on the processing conditions and materials.

2. Methods and Results

2.1. Experimental for ODS Treatment

Two kinds of Zr-based tubes, i.e. KNF-M and HANA-6, with an outer diameter of 9.5 mm and a wall thickness of 0.57 mm were used. Y_2O_3 was coated on the cleaned tubes by a spray coating method. To prepare the coating solution, Y_2O_3 nano-powder was dissolved in ethyl-alcohol at a solute content of 10%. The solution was mixed for 24 h using zirconia balls. The prepared solution was coated on zirconium tubes using a spray gun. The coated tubes were dried in atmospheric conditions for 24 h. To form the ODS layer, the Y_2O_3-coated cladding tubes were scanned by a laser beam. The diameter of the beam was 1 mm, and power of the beam was 180–200 W. The microstructure of the ODS layer was varied with axial speed (X_speed) and rotational speed (R_speed) of laser processing. To prevent oxidation, Ar gas was continuously blown on the samples' surfaces during laser processing. Cooling water was supplied to the inside of the tubes to release the induced heat. Fig. 1 shows the spray coated tube samples and the processing using a laser beam.

2.2. Microstructures

Fig. 2 shows the cross-sectional microstructures of the ODS treated KNF-M samples with the laser beam power of 180 and 200 W. It can be seen that the microstructure changes with respect to the axial speed (X) and rotational speed (R). The microstructure along the axial direction revealed the formation of an ODS layer 20–55 μm in thickness in the surface region. In addition, the thermal energy induced by a laser beam formed a heat-affected zone (HAZ) below the ODS layer. The ODS treatment layer was obvious, but HAZ formation was observed to be very large. Especially, when the laser processing speed is very low (X=0.3, R=4), it is observed that the base materials are all changed to HAZ. The depth of HAZ decreased with increasing rotational speed, and it did with decreasing axial speed at the same rotational speed. This is suggested to be a cooling effect by the Ar gas injected through the nozzle.

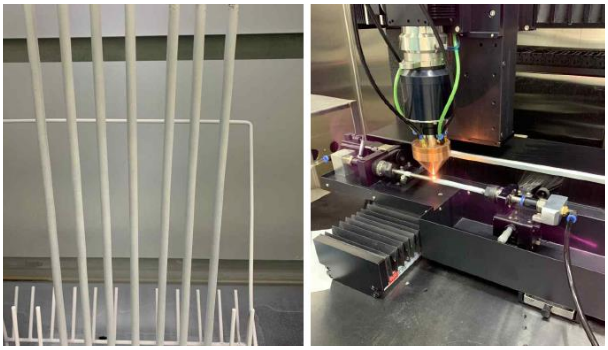

Fig. 1. Processing images: (left) spray coating, (right) laser beam scanning.

Fig. 3 shows the cross-sectional microstructures of the ODS treated HANA-6 samples with the laser beam power of 180 and 200 W. As a result of observing the change of process speed and the effect of laser power, the ODS layer was formed on the surface with a thickness of 20–55 μm, and HAZ was greatly developed. Below HAZ, the base material retains the original microstructure, and the portion of the base material that had not affected by heat was increased as the process speed is increased.

The microstructure of the cladding used in the experiment was completely recrystallized (RX) for KNF-M alloy and partially recrystallized (PRX) for HANA-6 alloy. Fig. 4 compares the results of ODS treatment of the two kinds of alloys under the same process condition. It can be seen that the width of the ODS and HAZ regions is larger in KNF-M than in HANA-6 alloy. This difference suggests that RX-structured KNF-M alloy was more sensitive to thermal effects than PRX-structured HANA-6 alloy due to the difference in the microstructure of the base material. It is considered that the selection of the initial microstructure for the ODS treatment will be an important factor because the behavior of he ODS surface treatment is changed according to the microstructure of the base material

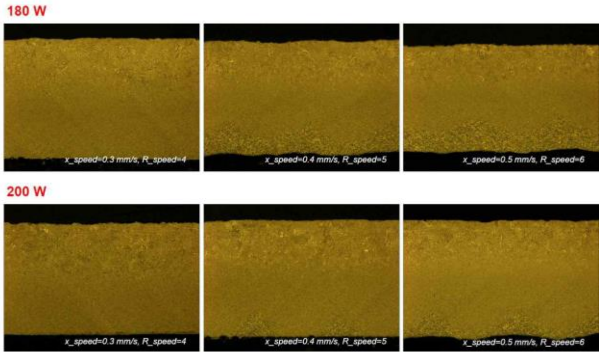

Fig. 2. Cross-sectional microstructures of KNF-M samples that ODS layer formed on their surface region.

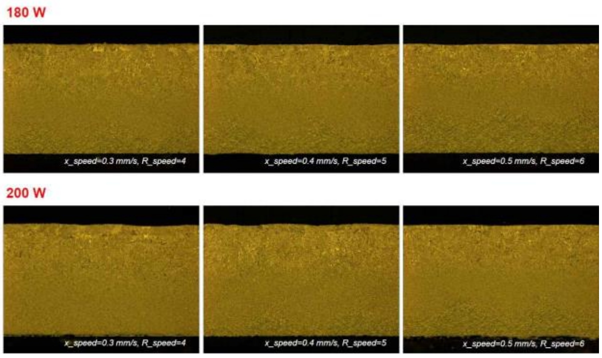

Fig. 3. Cross-sectional microstructures of HANA-6 samples that ODS layer formed on their surface region.

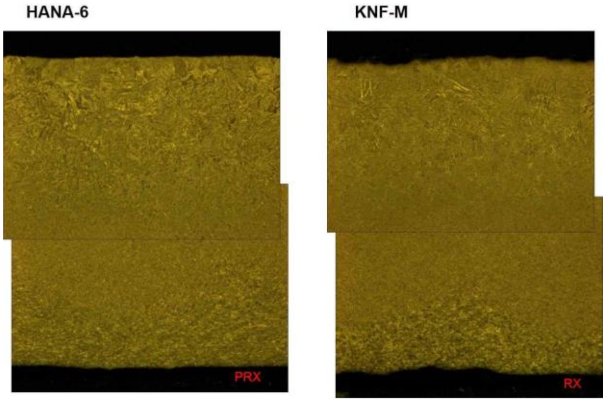

Fig. 4. SEM micrographs of ODS layer in HANA-6 samples.

3. Conclusions

Surface treatment was performed by a laser beam to form a dispersed oxide layer in KNF-M and HANA-6 Zr-based alloys. Laser beam scanning of a tube coated with Y_2O_3 resulted in the formation of a dispersed oxide layer in the tube's surface region. The thickness of ODS and HAZ could be controlled by process conditions.

Acknowledgment

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REFERENCES

[1] Y.-H. Koo et al., "KAERI's development of LWR accident-tolerant fuel," Nucl. Technol., 186, 295-304 (2014).
[2] H.-G. Kim et al., "Development status of accident-tolerant fuel for light water reactors in Korea," Nucl. Eng. Technol., 48, 1-15 (2016).
[3] H.-G. Kim et al., "Microstructure and mechanical strength of surface ODS treated Zircaloy-4 sheet using LBS," Nucl. Eng. Technol., 46, 521-528 (2014).
[4] Y.-I. Jung et al., "Strengthening of Zircaloy-4 using Y_2O_3 particles by a laser-beam-induced surface treatment process," Mater. Des., 116, 325-330, (2017).
[5] Y.-I. Jung et al., "Surface treatment to form a dispersed Y_2O_3 layer on Zircaloy-4 tubes," Appl. Surf. Sci., 429, 272-277, (2018).
[6] Y.-I. Jung et al., "Effect of a surface oxide-dispersion-strengthened layer on mechanical strength of zircaloy-4 tubes," Nucl. Eng. Technol., 50, 218-222, (2018).
[7] H.-G. Kim, I.-H. Kim, Y.-I. Jung, D.-J. Park, J.-H. Park, J.-H. Yang, Y.-H. Koo, "Microstructure and mechanical characteristics of surface oxide-dispersion-strengthened Zircaloy-4 cladding tube," Addit. Manufacturing, 22, 75-85, (2018).